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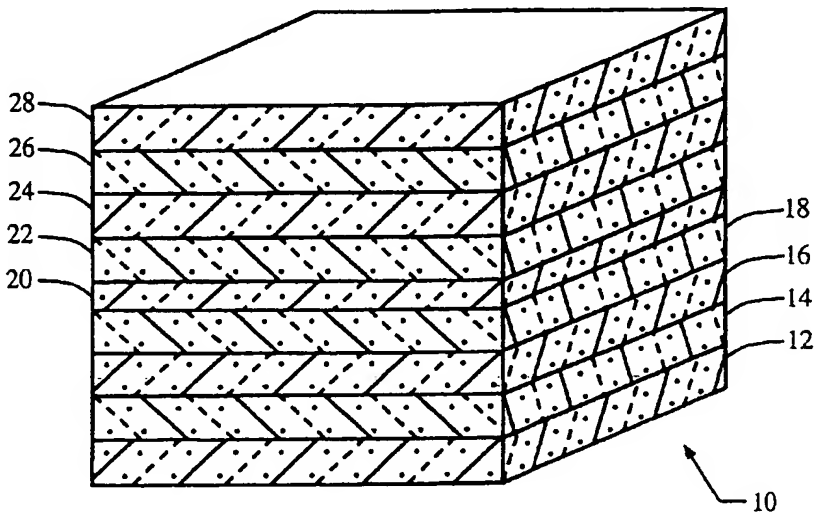
[Continued on next page]

(54) Title: CHARGE CONTROLLED AVALANCHE PHOTODIODE AND METHOD OF MAKING THE SAME



(57) Abstract: The present invention includes an epitaxial structure grown on a semi-insulating InP substrate. First, a buffer layer is grown to isolate defects originated from substrates. Then an n-type layer is grown to serve as n-contact layer to collect electrons. Next, a multiplication layer is grown to provide avalanche gain for the APD device. Following that, an ultra-thin charge control layer is grown with carbon doping. An absorption layer is grown to serve as the region for creating electronhole pairs due to a photo-excitation. Finally, a p-type layer is grown to serve as p-contact layer to collect holes.

WO 03/065417 A2

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

CHARGE CONTROLLED AVALANCHE PHOTODIODE AND METHOD OF MAKING THE SAME

FIELD OF THE INVENTION

[0001] The present invention relates generally to the field of semiconductor-based photodetectors, and more specifically to an optimized avalanche photodiode and a method of making the same.

BACKGROUND AND SUMMARY OF THE INVENTION

[0002] Owing to the known interaction between photons and electrons, great advances have been made in the field of photodetectors in recent years, particularly in those photodetectors that utilize semiconductor materials. One type of semiconductor-based photodetector is termed an avalanche photodiode, or APD. This type of structure is generally composed of a number of solid semiconductive materials that serve different purposes such as absorption and multiplication.

[0003] The APD structure provides the primary benefit of large gain through the action of excited charge carriers that produce large numbers of electron-hole pairs in the multiplication layer. However, an APD is so efficient at producing large numbers of charge carriers that it runs the risk of becoming saturated, thus adversely affecting the bandwidth of the device. In order to prevent charge carrier breakdown, it is imperative that the electric field be regulated within the APD itself, and in particular it is desirable to have the electric field in the multiplication layer be significantly higher than that in the absorption layer.

[0004] Traditionally, a separate absorption, grading, charge, multiplication (SAGCM) APD utilizes a grading layer to minimize hole trapping at the

heterojunction interface and a charge control layer to separate the electric field between the absorption and the multiplication layers. Design of this charge control layer is extremely critical in that it should allow for a high enough electric field strength to initiate impact ionization in the multiplication layer while keeping the electric field in the absorption layer low in order to prevent tunneling breakdown.

[0005] For example, an SAGCM APD structure with an n-type multiplication layer, electrons are multiplied and a p-type doping is required to act as the charge control layer. However, a conventional beryllium or zinc p-type doping method requires a relatively thick charge control layer because of the high diffusion coefficient associated with beryllium and zinc. Due to this thick charge control region with lower doping, the carrier transit time across the charge control layer is increased, thereby reducing the overall speed of these APD devices.

[0006] By way of comparison, in the present invention the limitations manifest in a beryllium or zinc charge control layer are overcome by utilizing carbon doping. This solution results in an ultra-thin charge control layer while increasing the speed of the photodetector. Since carbon has a very small diffusion coefficient, a precise doping control can be achieved to realize a charge sheet within an ultra-thin layer of 100 angstroms or less.

[0007] The present invention includes an epitaxial structure grown on a semi-insulating InP substrate. First, a buffer layer is grown to isolate defects originated from substrates. Then an n-type layer is grown to serve as n-contact layer to collect electrons. Next, a multiplication layer is grown to provide avalanche gain for the APD device. Following that, an ultra-thin charge control layer is grown with carbon doping. An absorption layer is grown to serve as the region for creating electron-

CLAIMS

1. An avalanche photodiode comprsing:
an absorption layer disposed on a substrate layer;
a multiplication layer disposed on the substrate layer; and
a carbon-doped charge control layer disposed between the absorption layer and the multiplication layer.

2. The avalanche photodiode of claim 1 wherein the absorption layer is disposed between a first digital graded layer and a second digital graded layer.

3. The avalanche photodiode of claim 1 further comprising an n-type contact layer disposed between the multiplication layer and the substrate.

4. The avalanche photodiode of claim 1 further comprising a p-type contact layer.

5. The avalanche photodiode of claim 1 further comprising a buffer layer disposed between the n-type contact layer and the substrate.

6. The avalanche photodiode of claim 1 wherein the absorption layer is InGaAs.

7. The avalanche photodiode of claim 1 wherein the multiplication layer is InAlAs.

8. The avalanche photodiode of claim 1 wherein the carbon-doped charge control layer is carbon-doped InAlAs.

9. The avalanche photodiode of claim 1 wherein the carbon-doped charge control layer is between 2 and 100 angstroms in thickness.

10. The avalanche photodiode of claim 1 wherein the carbon-doped charge control layer is between 5 and 50 angstroms in thickness.

11. The avalanche photodiode of claim 1 wherein the carbon-doped charge control layer is between 5 and 35 angstroms in thickness.

12. The avalanche photodiode of claim 2 wherein the first digital graded layer is InAlGaAs, and further wherein the second digital graded layer is InAlGaAs.

13. The avalanche photodiode of claim 3 wherein the n-type contact layer is one of InP or InAlA.

14. The avalanche photodiode of claim 4 wherein the p-type contact layer is one of InP or InAlAs.

15. A method of fabricating an avalanche photodiode comprising the steps of:

providing a substrate layer;
depositing a multiplication layer;
depositing a carbon-doped charge control layer; and
depositing an absorption layer.

16. The method of claim 15 further comprising the step of depositing an n-type layer to collect electrons.

17. The method of claim 15 further comprising the step of depositing a p-type layer to collect holes.

18. The method of claim 15 further comprising the step of depositing a digital grading layer to prevent carrier trapping between bandgap offsets.

19. The method of claim 15 further comprising the step of doping an InAlAs material with carbon.

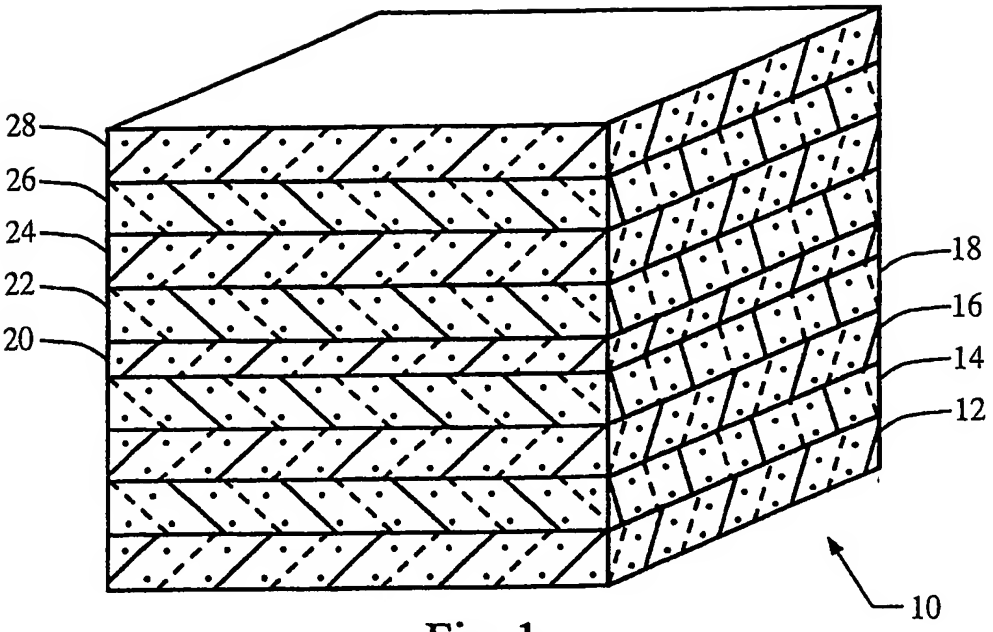

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Fig. 1

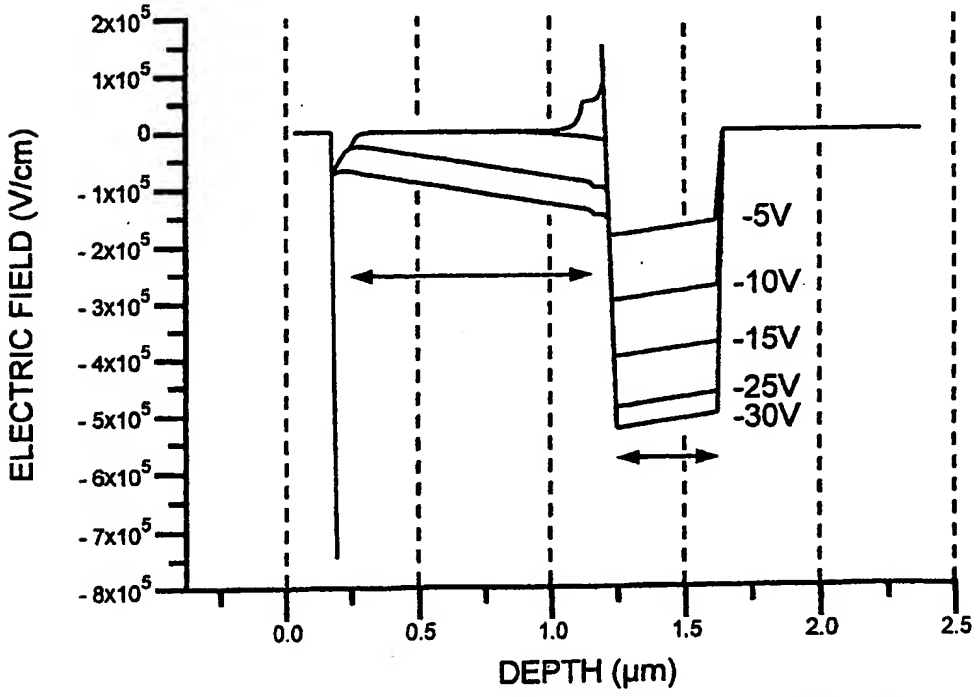
2x10^5
1x10^5
0
-1x10^5
-2x10^5
-3x10^5
-4x10^5
-5x10^5
-6x10^5
-7x10^5
-8x10^5
ELECTRIC FIELD (V/cm)
0.0
0.5
1.0
1.5
2.0
2.5
DEPTH (μm)
-5V
-10V
-15V
-25V
-30V

Fig. 2

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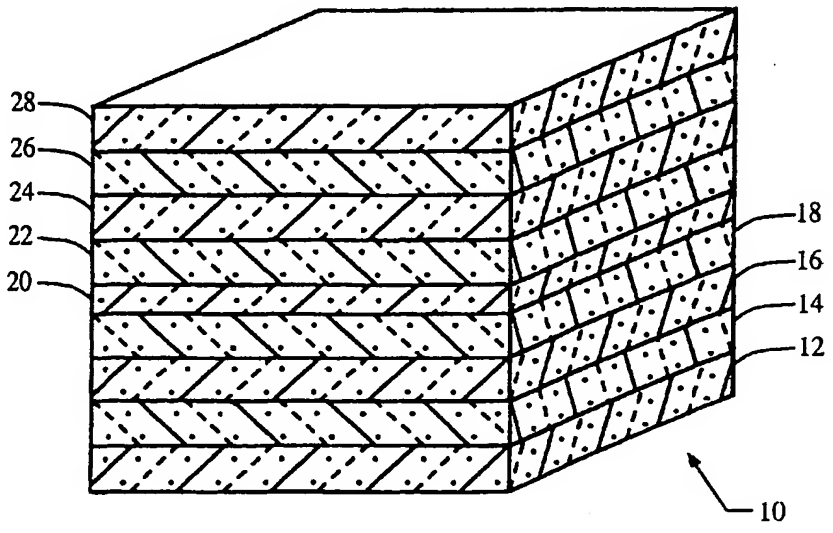

(57) Abstract: The present invention includes an epitaxial structure (16) grown on a semi-insulating InP substrate (12). First, a buffer layer (14) is grown to isolate defects originated from substrates (12). Then an n-type layer (18) is grown to serve as n-contact layer to collect electrons. Next, a multiplication layer (20) is grown to provide avalanche gain for the APD device (10). Following that, an ultra-thin charge control layer (22) is grown with carbon doping. An absorption layer (24) is grown to serve as the region for creating electronhole pairs due to a photo-excitation. Finally, a p-type layer (28) is grown to serve as p-contact layer to collect holes.

WO 03/065417 A3

INTERNATIONAL SEARCH REPORT

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PCT/US03/03203

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : H01L 21/18; H01L 31/107
US CL : 257/186; 257/438
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
STN; Dialog; EAST

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6,326,650 B1(ALLAM) 04 December 2001 (04.12.2001), columns 1-33.	1-19
X	US 5,654,578 A (WATANABE) 05 August 1997 (05.08.1997), ccolumn 8, lines 25-68.	1-19
A	US 5,365,077 A (METZGER et al.) 15 November 1994 (15.11.1994), columns 1-7	1-19

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 May 2003 (14.05.2003)	28 AUG 2003
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450 Alexandria, Virginia 22313-1450 Facsimile No. (703)305-3230	Authorized officer W. David Coleman Telephone No. 703-308-0956

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